

Oct. 1, 1946.

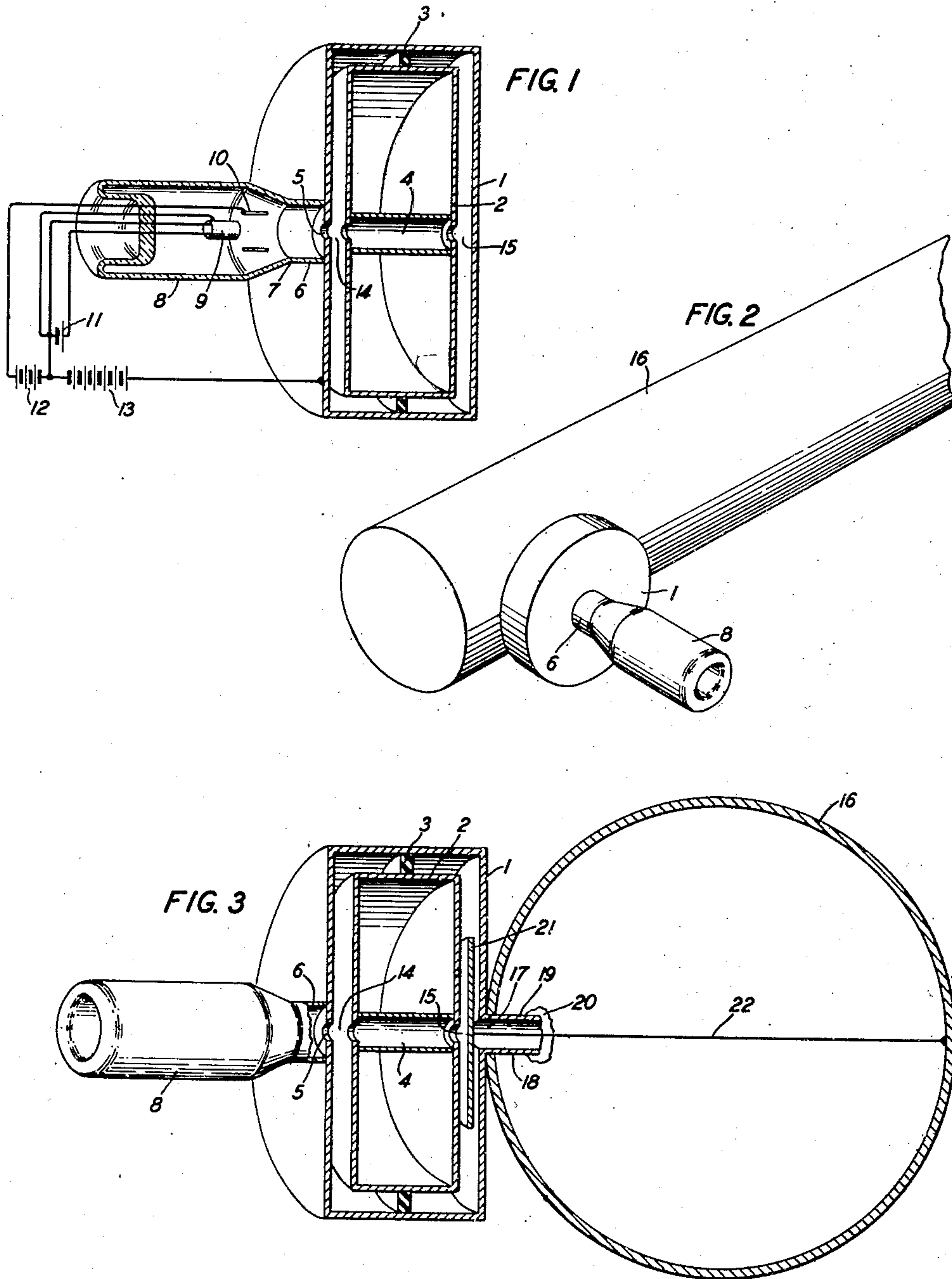
A. E. BOWEN

2,408,409

ULTRA HIGH-FREQUENCY ELECTRONIC DEVICE

Filed April 8, 1941

4 Sheets-Sheet 1



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FIG. 4

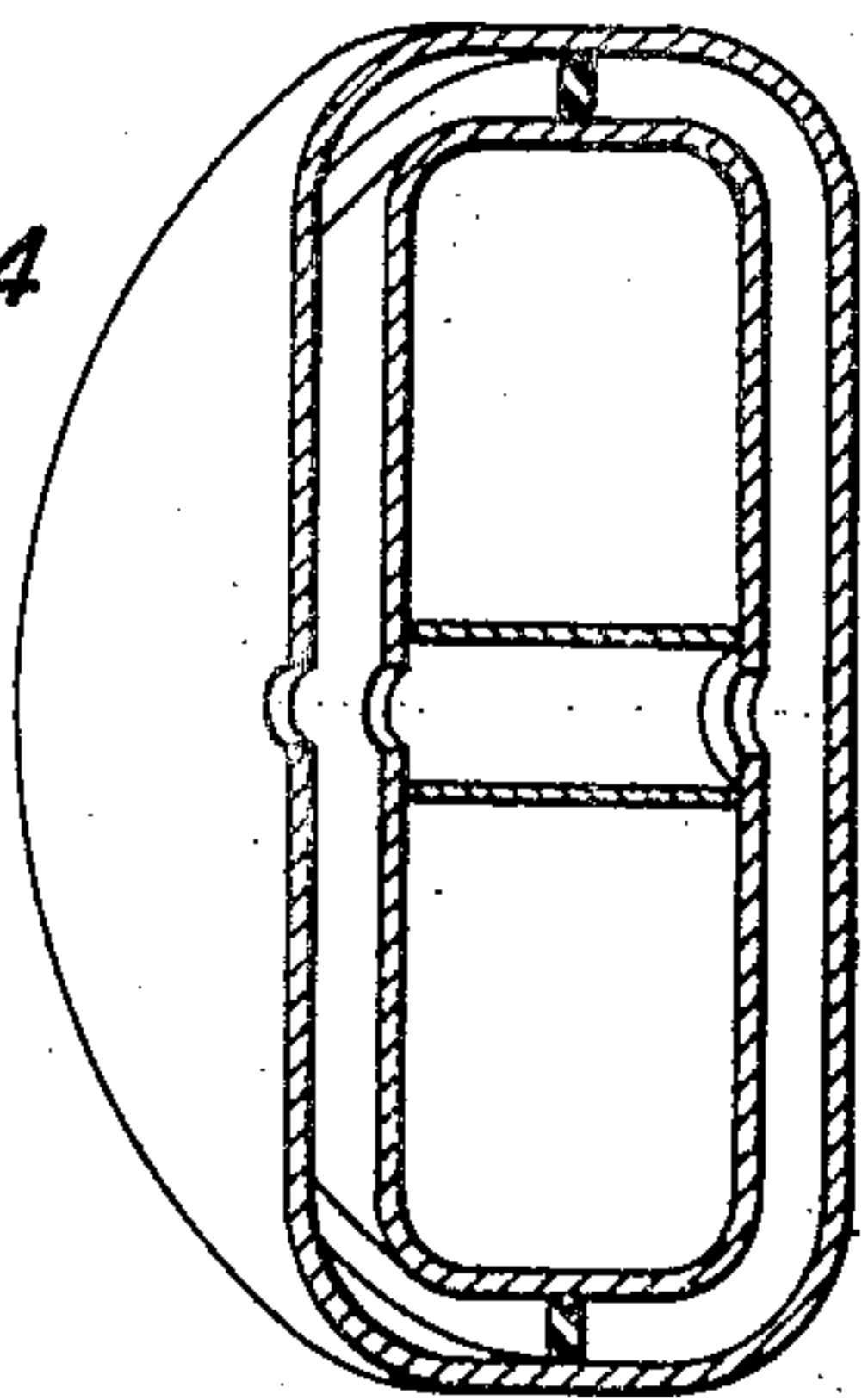


FIG. 5

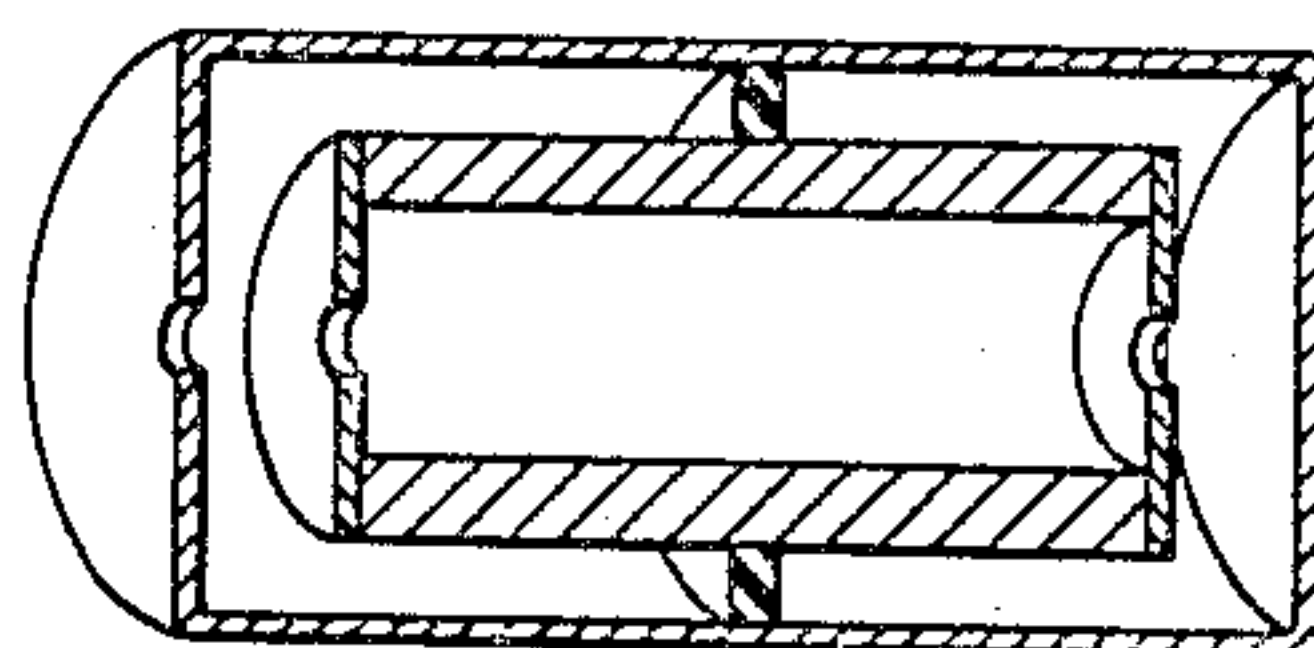


FIG. 6

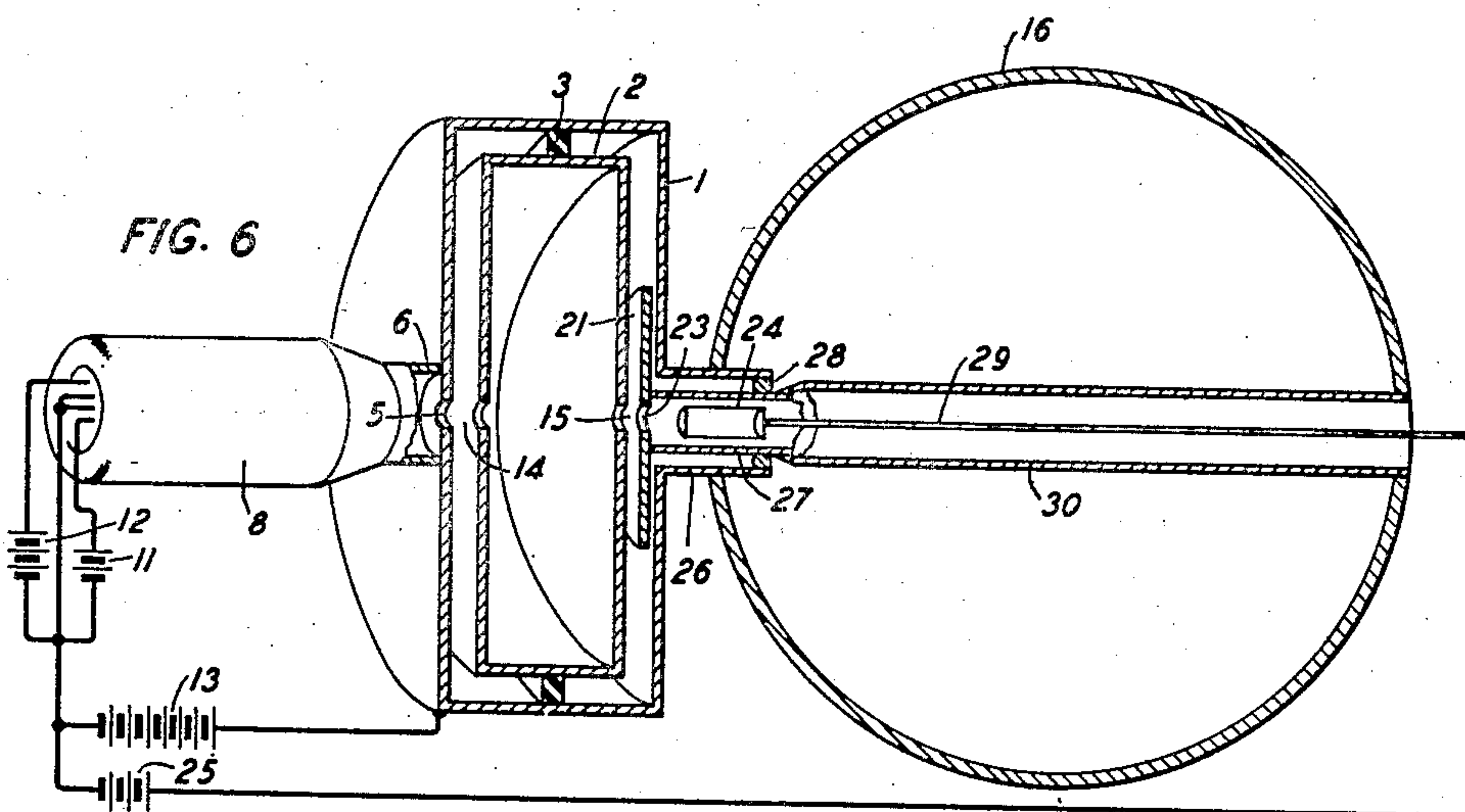


FIG. 7

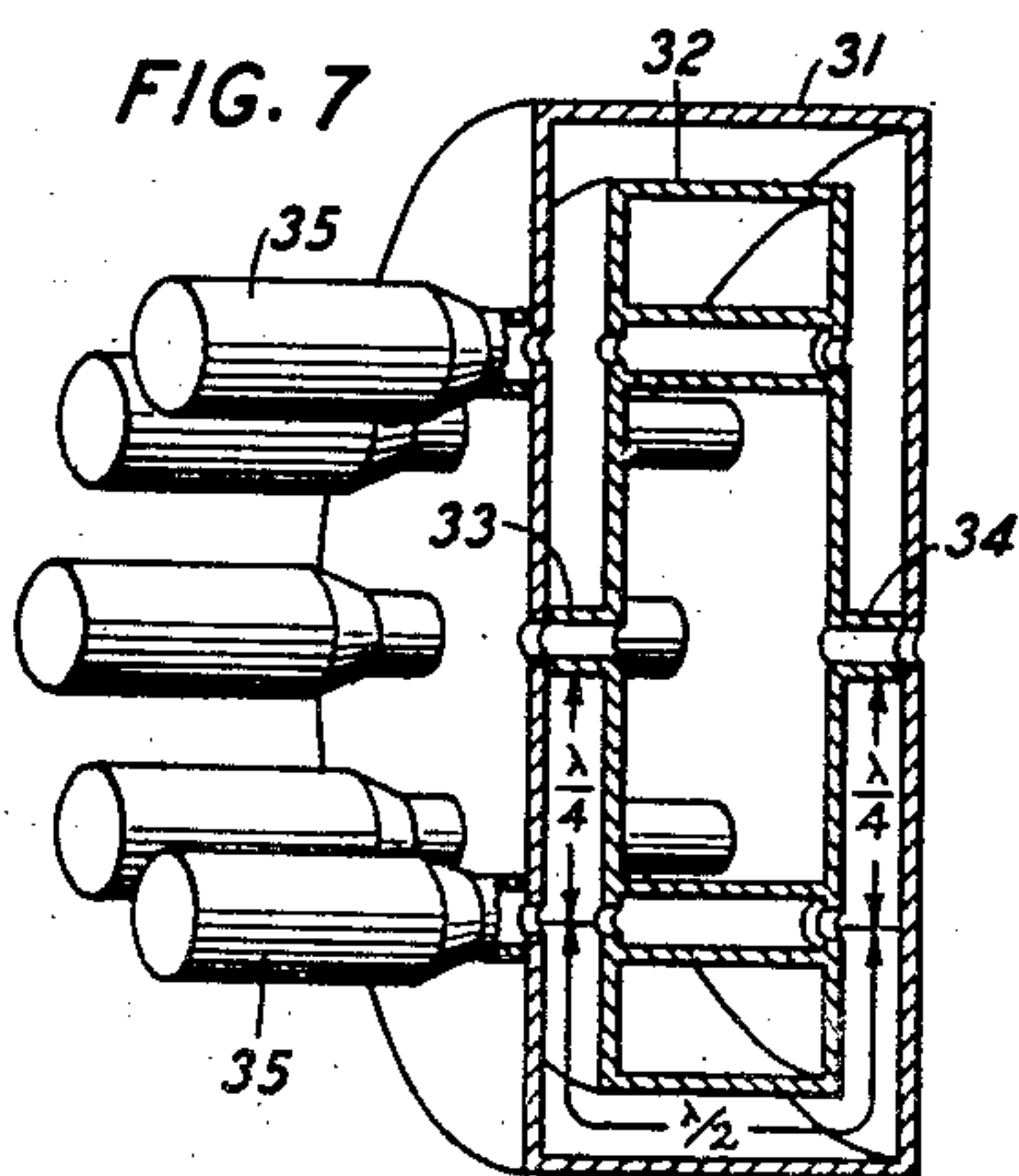


FIG. 8

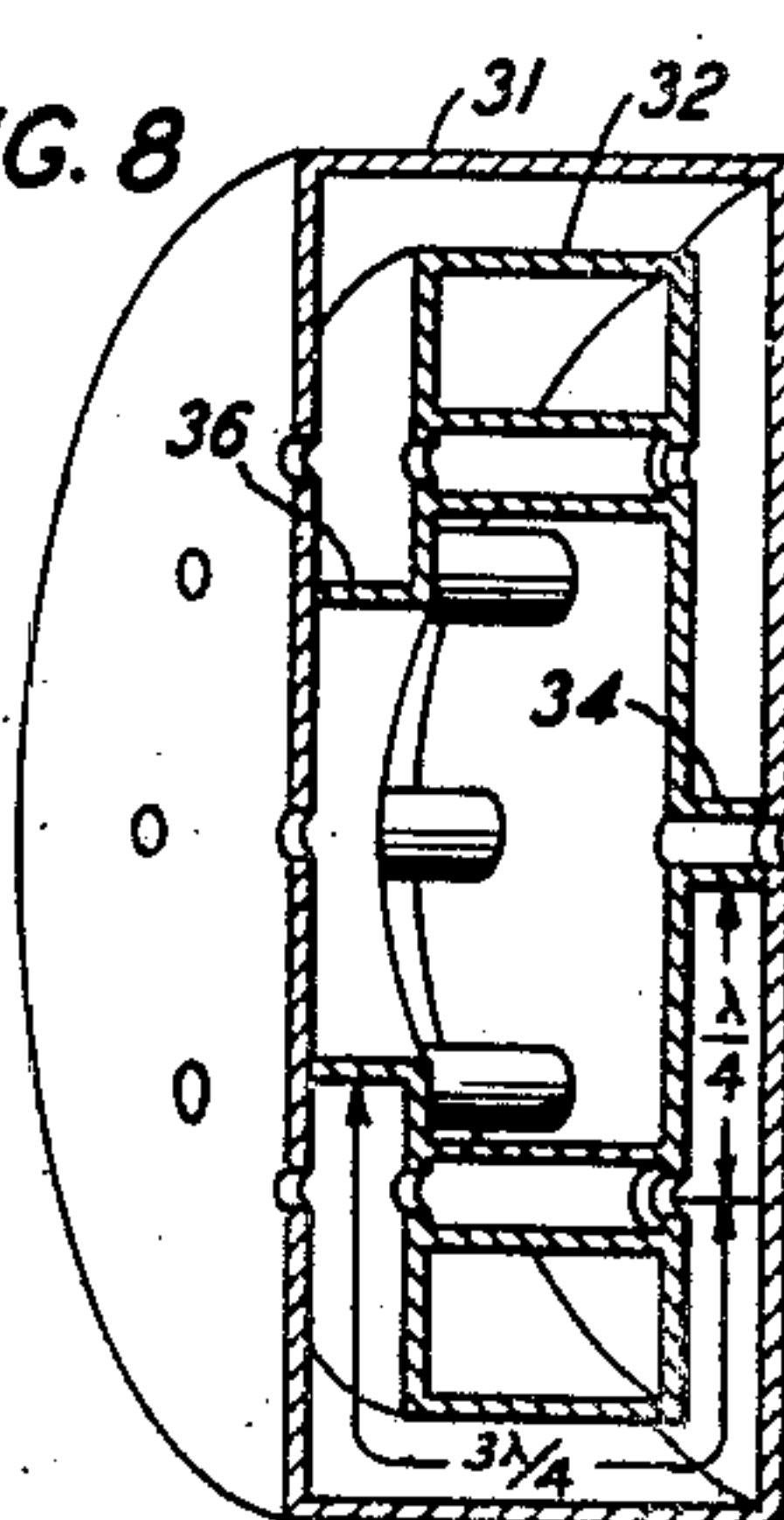
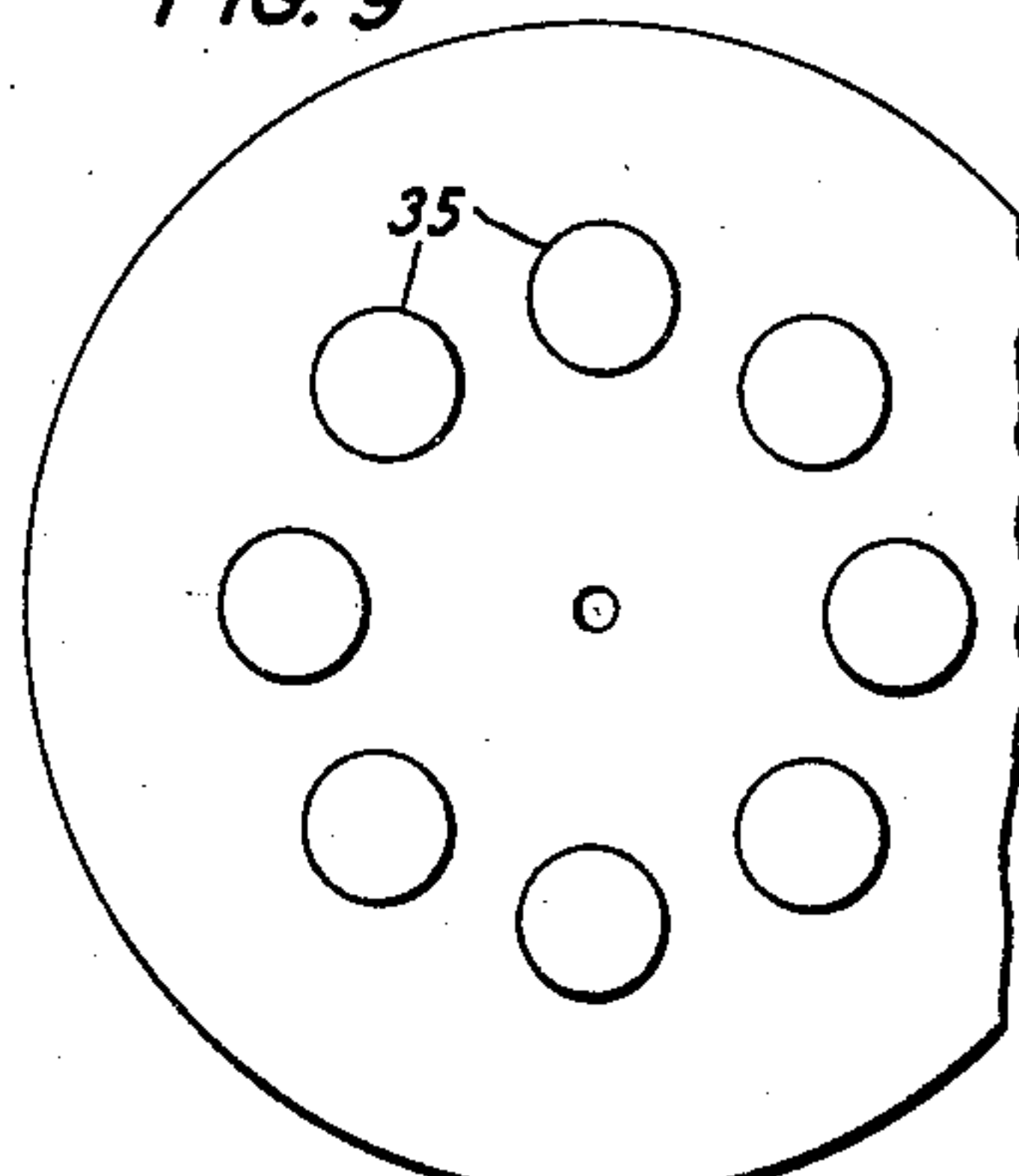


FIG. 9



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FIG. 10

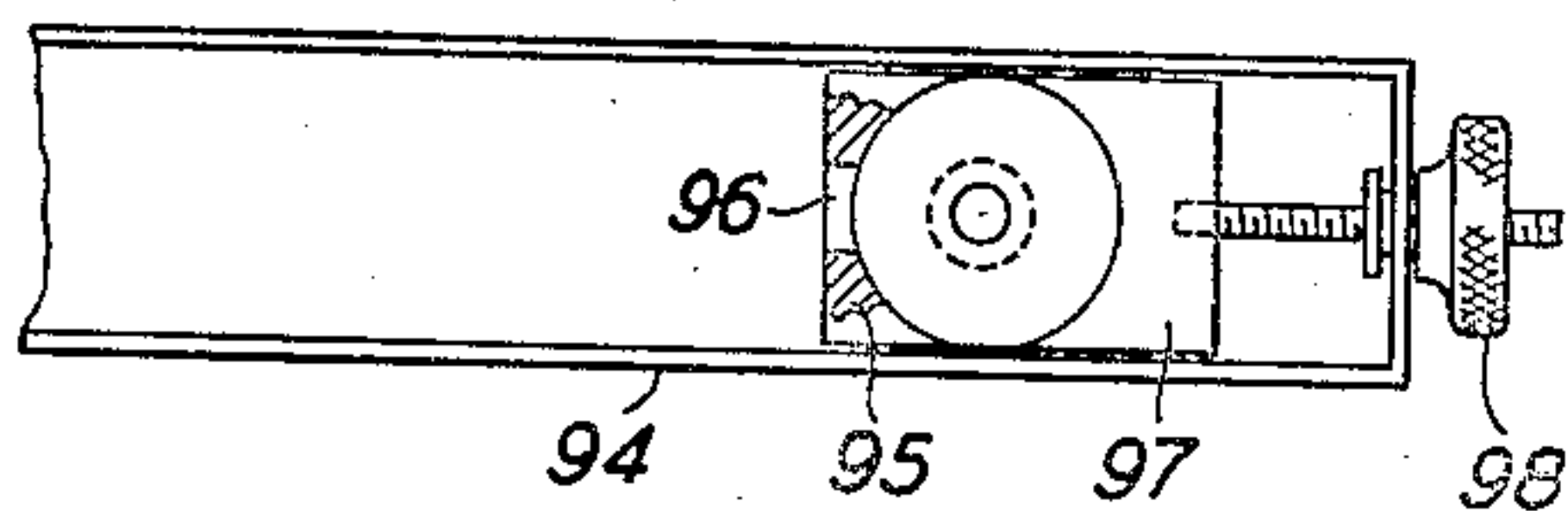


FIG. 11

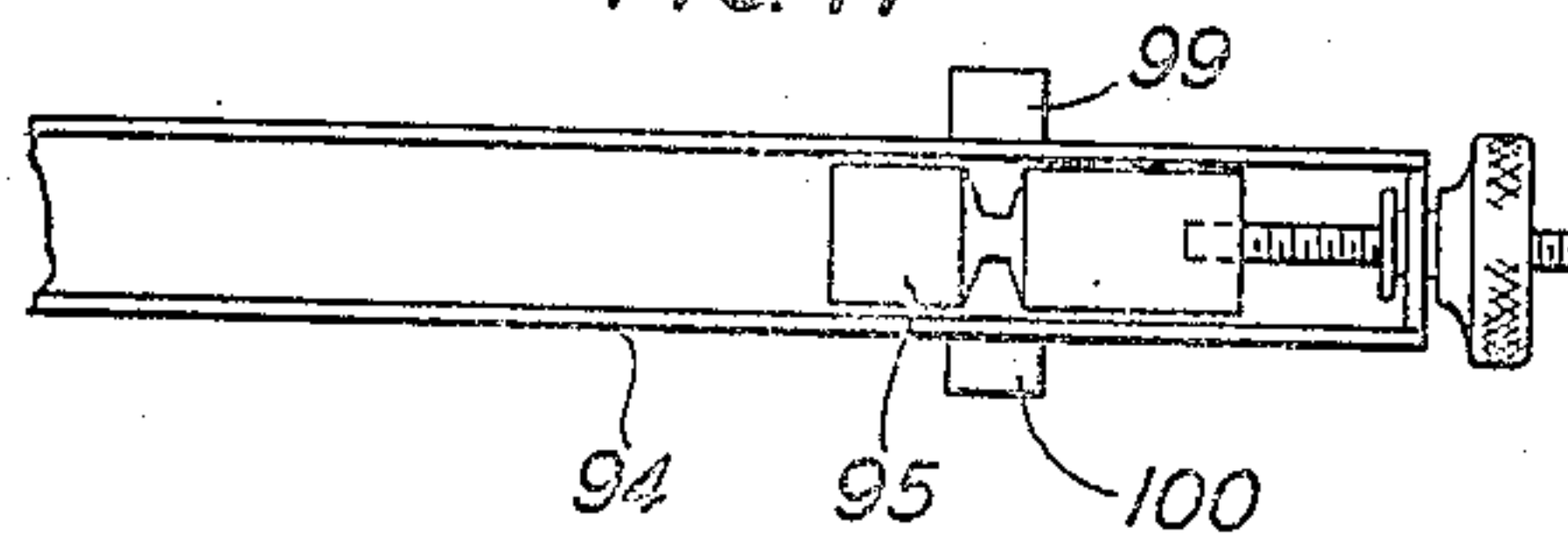


FIG. 12

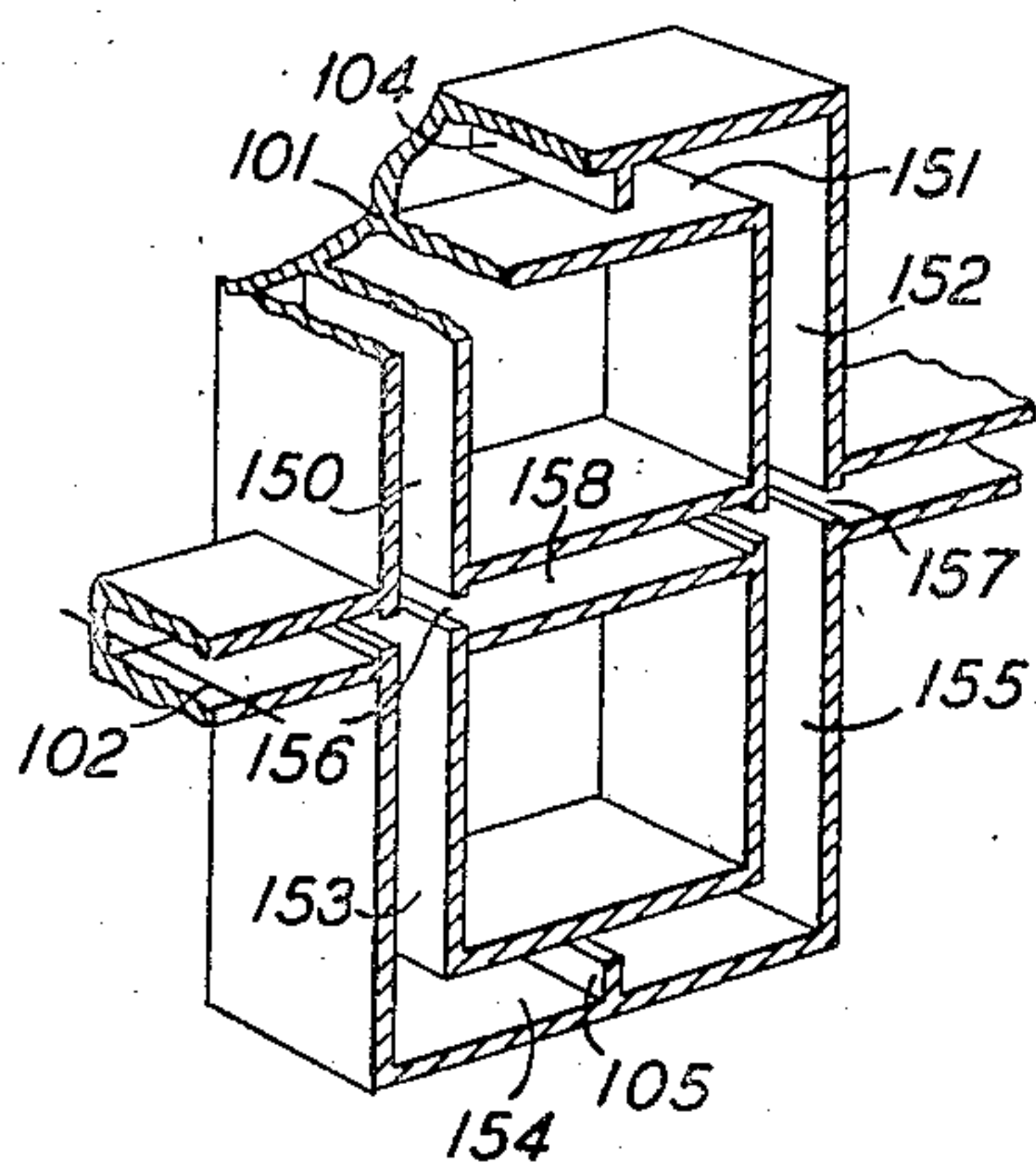


FIG. 13

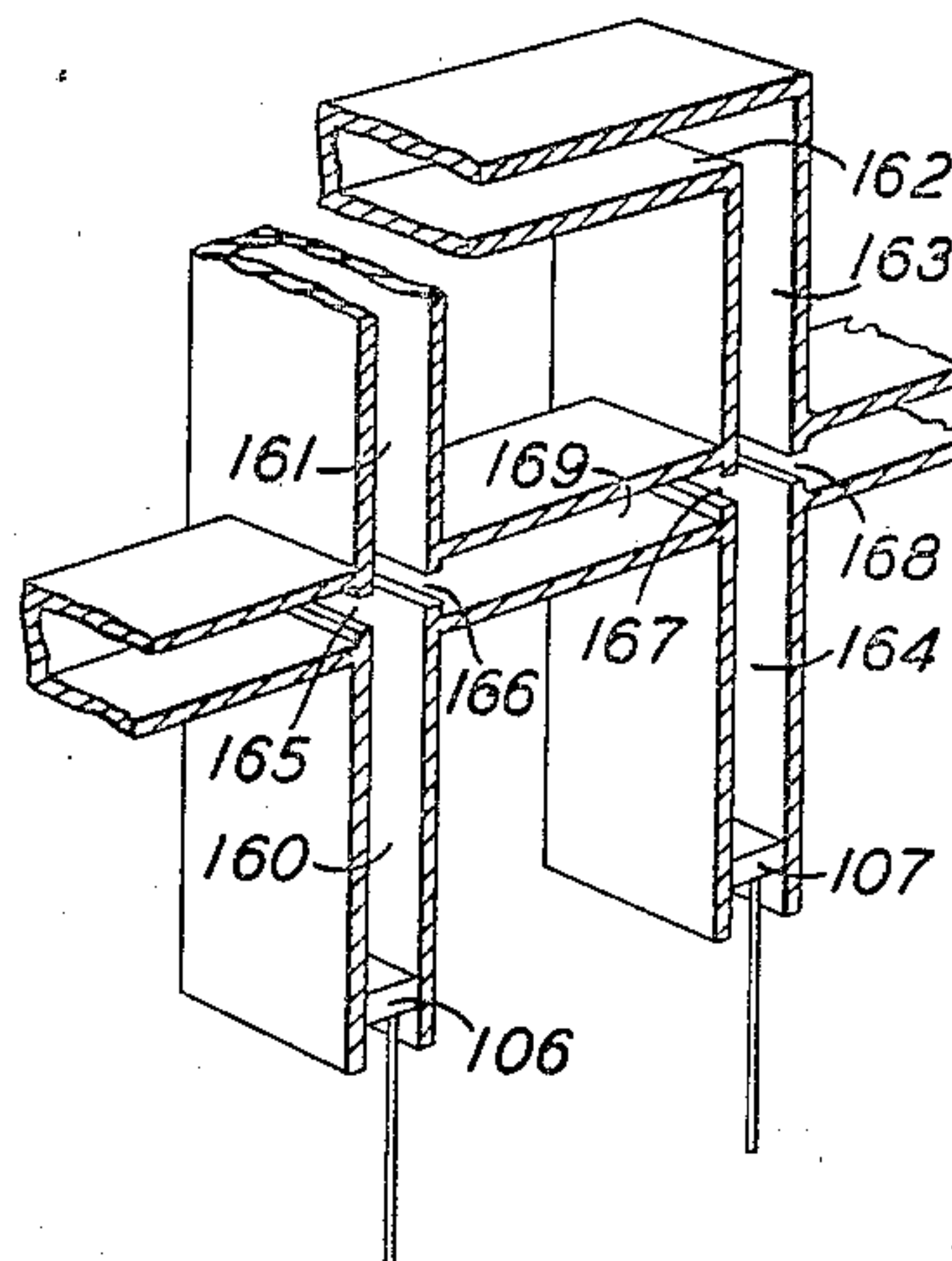


FIG. 14

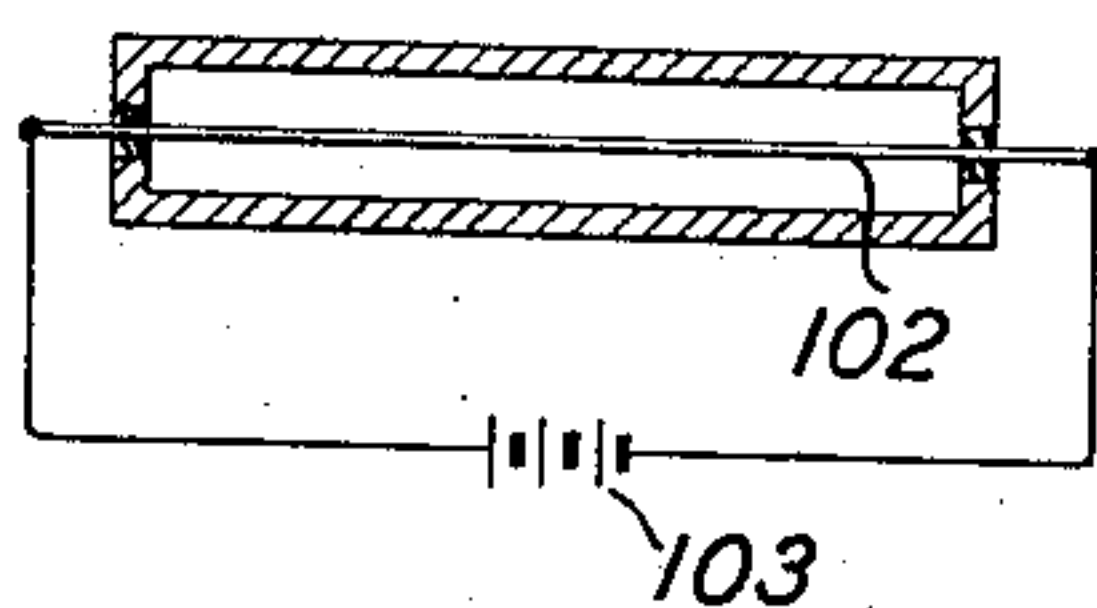
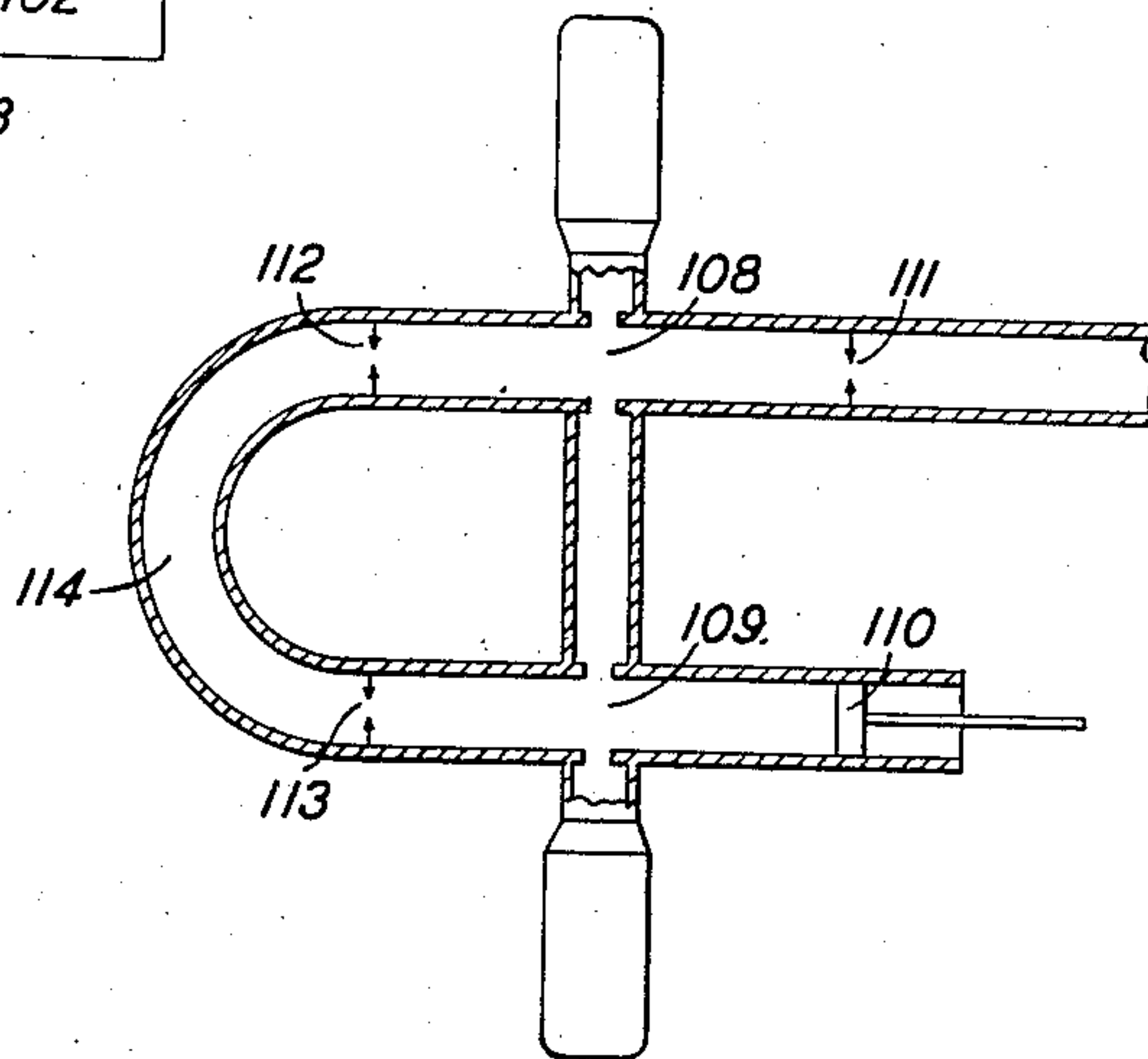


FIG. 17



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FIG. 15

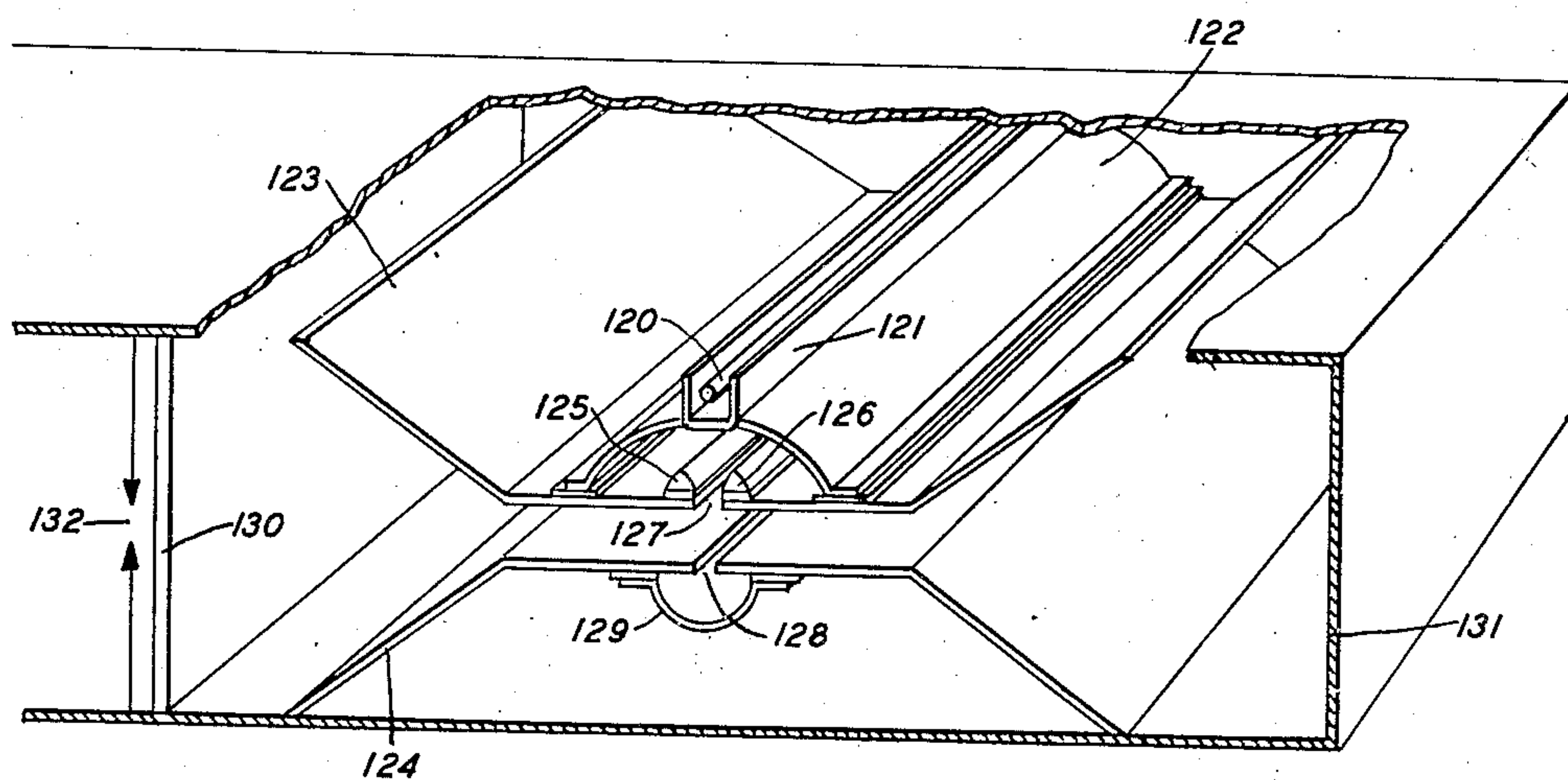


FIG. 16

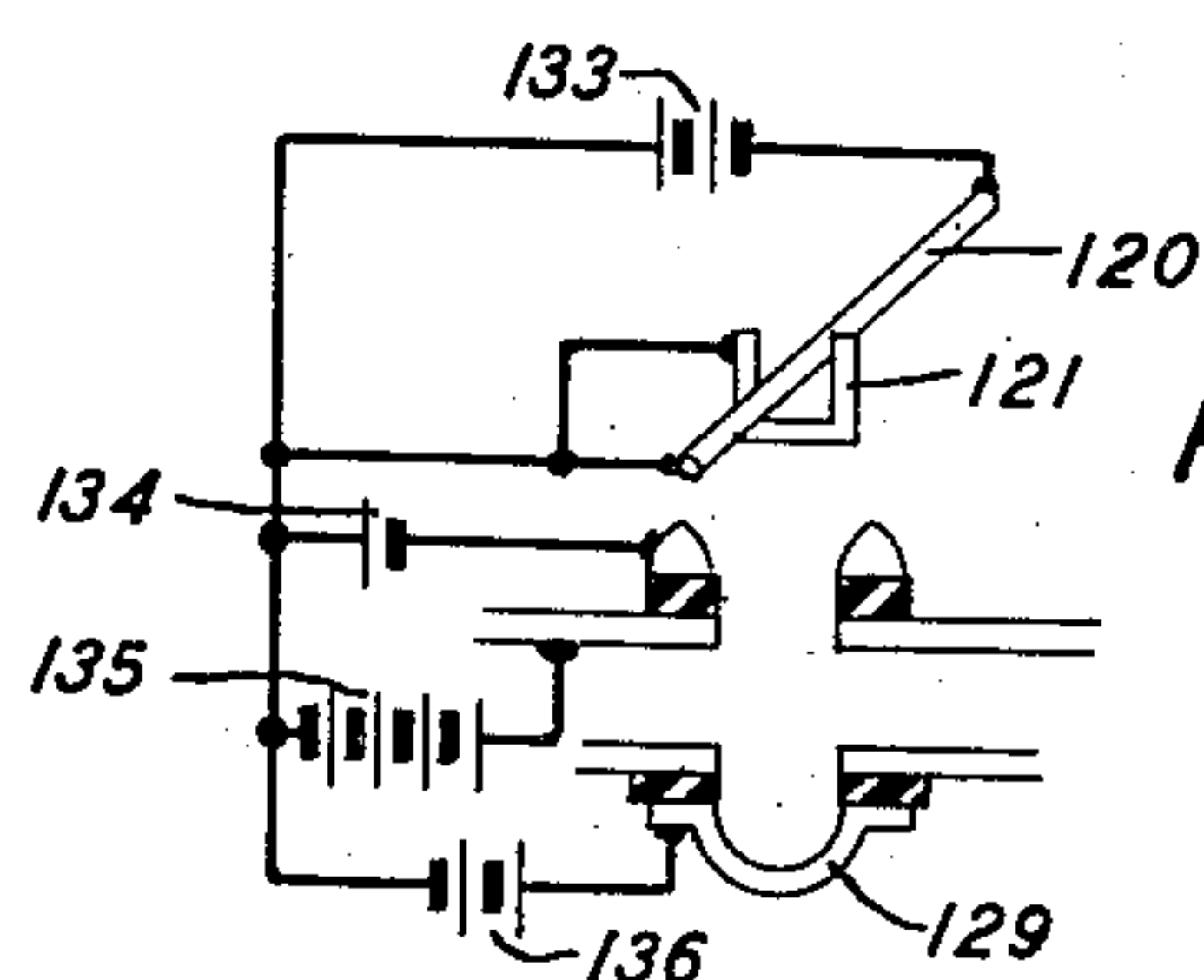
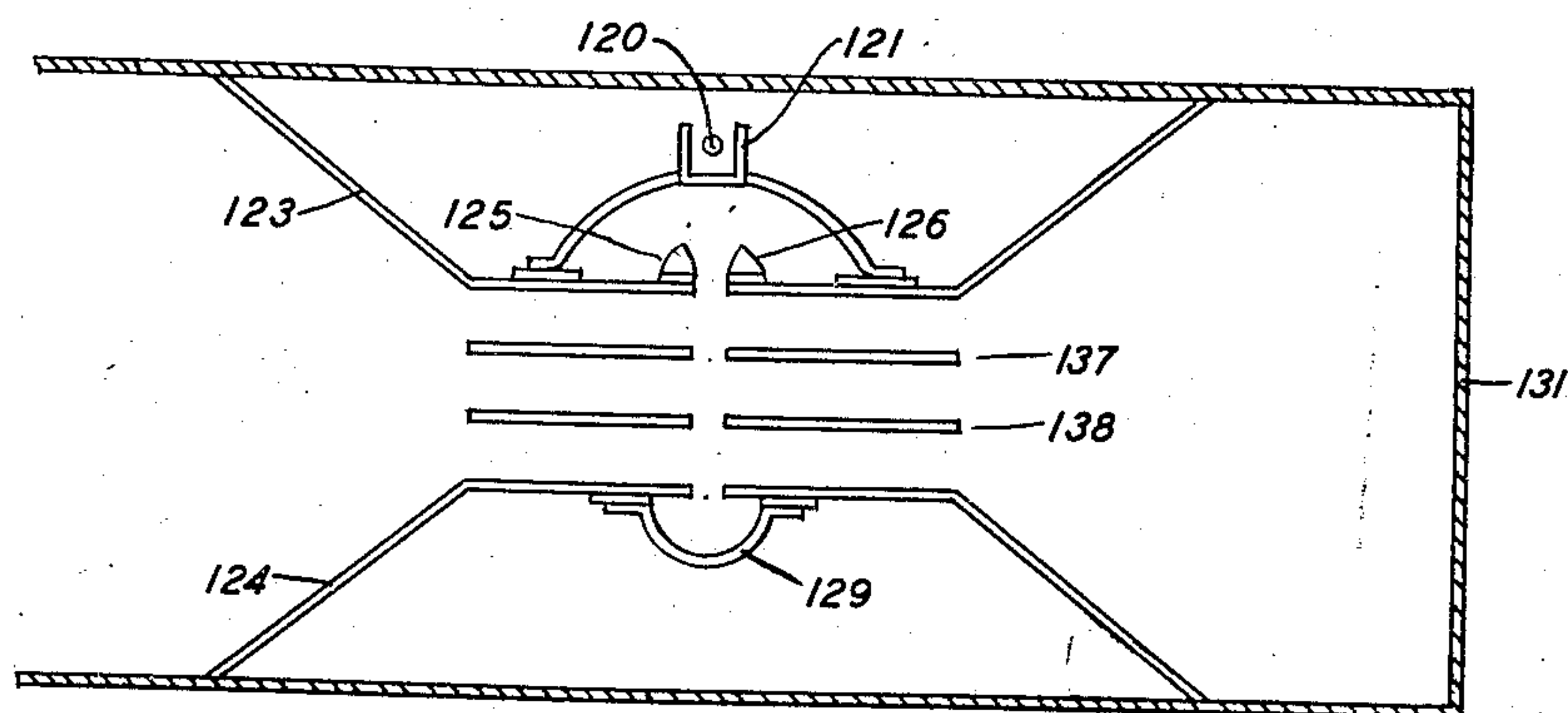


FIG. 15A

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UNITED STATES PATENT OFFICE

2,408,409

ULTRA HIGH FREQUENCY ELECTRONIC
DEVICE

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York, N. Y., a corporation of New York

Application April 8, 1941, Serial No. 387,432

14 Claims. (Cl. 315—5)

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This invention relates to resonators and resonant cavities so shaped and constructed as to be suitable for use with an electron stream to enable an electromagnetic field which may be set up in the resonator or resonant cavity to induce a variation in some characteristic property of the electron stream, or, in general, to permit an interchange of energy between the resonator and the electron stream.

In particular, it relates to arrangements for facilitating interchange of energy between an electron stream and an electromagnetic field in a resonant cavity and for coupling such a resonator to an extended wave guide for energy transmission or reception. The wave guide may be of any suitable form, as, for example, a hollow conductive tube containing air, or a rod of dielectric material, etc.

The resonators employed in various embodiments of the invention are of a number of types. For example, the resonant cavity may consist of the space between two concentric cylindrical conductive shells of slightly different radii and slightly different lengths, each of the shells being closed at both ends by conductive discs except for such apertures or perforations as may be required for coupling purposes. Another form of resonator which is particularly well adapted for coupling between a wave guide and an electron stream is formed by partitioning off a section of the wave guide of proper length to serve as a resonator at the desired operating frequency. Wave guides of either rectangular or circular cross section are most conveniently used although the invention is not limited to any particular shape or size of guide.

The methods of coupling the resonator to the wave guide that may be used in accordance with the invention are various. A resonator may be coupled into the side of a cylindrical wave guide through a connecting tube. In the case of a resonator partitioned off within an extended wave guide the coupling may be by way of an aperture in the partition wall and the amount of the coupling may be made adjustable by means of an iris or other means of varying the size of the aperture.

Openings for the passage of the electron stream are generally provided at voltage anti-nodes of the electric field in order to secure the maximum interchange of energy. In one arrangement a plurality of electron streams are arranged in a ring concentric with the axis of a resonator, or a tubular-shaped electron stream may be employed.

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The invention is applicable generally to amplifiers, oscillators, modulators, detectors and the like, particularly at ultra-high frequencies, wherever it is desired to effect direct interaction between an electromagnetic field and an electron stream.

The invention is described with reference to a number of illustrative examples.

In the drawings:

Fig. 1 is a perspective view, partly in cross section and partly diagrammatic, showing an electron tube oscillator having a cavity resonator comprising concentric cylindrical shells;

Fig. 2 is a general perspective view of an oscillator of the type shown in Fig. 1, coupled to a long cylindrical wave guide;

Fig. 3 is a cross-sectional view partly in perspective with a detailed showing of one arrangement for coupling the oscillator to the wave guide;

Figs. 4 and 5 show alternative forms of resonators comprising concentric cylindrical shells;

Fig. 6 shows another method of coupling an oscillator of the type shown in Fig. 1 to a wave guide and differs somewhat in detail from the arrangement shown in Fig. 3;

Figs. 7 and 8 show variations of an oscillator of the type shown in Fig. 1 modified so as to accommodate a plurality of electron streams;

Fig. 9 is an end view of an oscillator as in Fig. 7 or Fig. 8 showing the arrangement of the vacuum tubes in a circular array;

Figs. 10 and 11 show a top view and a side view, respectively, partially in cross section, of a cavity resonator consisting of a compartment partitioned off from the main portion of a wave guide, the compartment having two semicircular walls one of which is slidably mounted for tuning purposes;

Figs. 12 and 13 show perspective views partially in cross section of resonators employing sections of rectangular wave guides and accommodating a linearly extended electron stream;

Fig. 14 is a detailed cross-sectional view of a cathode installation suitable for use with the structures of Figs. 12 and 13;

Fig. 15 is a perspective view, partially cut away, of a form of diode oscillator built into a rectangular wave guide;

Fig. 15A is a diagram useful in explaining the construction of and electrical connections to the oscillator of Fig. 15;

Fig. 16 is a longitudinal cross-sectional view of a modification of the arrangement shown in Fig. 15; and

Fig. 17 shows an oscillator employing a wave

guide which is bent in a U-shape in order to intercept an electron stream at two points.

In Fig. 1 there is shown a cylindrical can 1 comprising conductive cylindrical walls and conductive plane end plates. Supported within the can 1 is a coaxial cylinder 2 also conductive and with plane ends. The cylinder 2 is illustrated as being hollow but may be solid if desired. The inner cylinder 2 is supported and separated from the can 1 by an insulating ring 3, one face of which may be given a thin metallic coating which will provide conductive connections between the can 1 and cylinder 2 with negligible obstruction to the passage of electromagnetic waves throughout the space or cavity between the cylinders. The latter may be made of copper or other suitable conductive material. Cylinder 2 is provided with an axial shielded passageway or tube 4 and the left-hand face of cylinder 1 is pierced by a coaxial hole 5. A copper tube or other hollow conductive cylinder 6 is fastened to the left-hand face of cylinder 1 and the tube 6 is joined by means of a suitable hermetic seal 7 to a glass or other suitable insulating envelope 8. Within the envelope 8 are provided the elements of an electron gun of any suitable type comprising, for example, a cathode 9, and an accelerating electrode 10 cooperating with the cylinder 6 to direct an electron beam through the hole 5 and the aligned holes at the ends of the passage or tube 4. Gaps 14 and 15 are constituted as indicated in the path of the beam. The gap 14 is constituted between the edges of the hole 5 and the left-hand end of tube 4, and the gap 15 is constituted between the right-hand end of tube 4 and the inner surface of the can 1. Batteries 11, 12 and 13 are provided respectively for heating the cathode 9, energizing the accelerating electrode 10 and applying an accelerating potential to the metallic or conductive system comprising the cylinders 1, 2 and 6, although other suitable energizing means may be substituted.

In the operation of the system of Fig. 1, oscillations are maintained in the resonant system comprising the space between cylinders 1 and 2 by means of interaction between the electron stream and electromagnetic waves in the resonator. Physically the action of the device may be thought of as follows: In their passage across the gap 14, the electrons either take from or give energy to the high frequency electromagnetic field in the resonant cavity depending upon the phase of the field during their transit across the gap. The velocities of the electrons are varied in accordance with the energy interchange in well-known manner. Then the electrons pass through the passageway or tube 4 where a grouping or bunching effect takes place, those electrons which have lost energy and have as a consequence been slowed up, being overtaken by other electrons which have entered later, have gained energy and thus been speeded up. Consequently at a point some distance to the right of the gap 14, the electrons are traveling in more or less well-defined groups. Upon reaching the second gap 15 the bunches of electrons may, if the length of the passageway 4 and the initial speed of the electrons have been adjusted correctly, cross the gap 15 in opposition to the high frequency electromagnetic field, thus contributing energy to the field, and in greater amounts than that absorbed by the thinly distributed electrons which may cross the gap 15 during the unfavorable phase of the high frequency field.

It is usually desirable that the steady com-

ponent of the potential of the cylinder 2 be the same or nearly the same as that of cylinder 1. To secure this condition, one face of the insulating or dielectric ring 3 may be coated with a thin film of conducting material. Experiments with such films in connection with wave guides have indicated that a film can be made to give sufficiently high conductivity for maintaining the steady component of potential without impeding seriously the passage of the high frequency wave through the film. Alternatively the ring 3 may be replaced if desired by one or more rods or studs of conductive material preferably spaced evenly about the periphery of the cylinder 2.

An oscillator of the type shown in Fig. 1 may be coupled to a wave guide for transmission to a distant point. One coupling arrangement is illustrated generally in Fig. 2 wherein 16 is a circular wave guide to one side of which is attached the cylinder 1. The details of the coupling between the oscillator and the wave guide may be arranged in a variety of ways, one of which is shown in Fig. 3.

The wave guide 16, illustrated as being a conductive tube, is shown in cross section in Fig. 3. The resonant chamber, electron gun arrangements and other details of the oscillator are similar to those shown in Fig. 1 with the principal exception of a change in the right-hand wall of cylinder 1. An axial hole 17 is cut through this wall and a metallic or conductive tube 18 is fastened over the hole. The end of the tube 18 is sealed off, as, for example, by a metal glass seal 19 and a glass bead 20 so as to complete the closure of the vacuum chamber. Inside cylinder 1 is placed a disc 21 of conductive material parallel to the face of cylinder 1 and separated from it by a small gap. A conductive rod 22 is provided which serves to support the disc 21 and is in turn held in position and sealed in the bead 20.

In the system of Fig. 3 oscillations are maintained in the resonant cavity in the manner described in connection with Fig. 1 and in addition it is apparent that a portion of the high frequency energy resident in the resonant cavity will escape through the gap between disc 21 and cylinder 1 and will be available for use in outside circuits. In the arrangement illustrated in Fig. 3, the outside circuit is the wave guide 16. The rod 22 is placed across a diameter of the guide 16 and serves to establish a transverse electric or H_{11} wave in the guide 16 in a well-known manner.

The resonator of Fig. 1 or Fig. 3 operates with voltage anti-nodes at the gaps 14 and 15, the insulating ring 3 being located at a voltage node in the equatorial plane. It is evident, therefore, that in designing the resonator for working at a predetermined frequency, the effective length of the cavity between the cylinders 1 and 2 from the gap 14 to the gap 15 should be made substantially a half wave-length. The wave-length referred to here is, of course, determined by the velocity of propagation of the wave in the cavity. The best dimensions for a given frequency may well be determined by trial or if it is not necessary that the frequency be predetermined, the cylinders may be built of convenient size and the resulting operating frequency determined with a wave meter or other suitable means.

Fig. 4 shows a modified resonator having the corners of the cylinders rounded off to provide a smoother passage for the waves and thus reduce power losses.

Fig. 5 shows a cavity resonator employing cyl-

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inders of somewhat different proportions from those shown in the preceding figures.

Fig. 6 shows an arrangement similar to that of Fig. 3 except that provision is made for slowing down the electrons before collection at the anode. In the arrangements of Figs. 1 and 3, the electric fields in the gap 15 will usually not be sufficiently strong to produce the ideal condition in which many of the electrons would be brought almost to rest and would strike the right-hand wall of cylinder 1 in the arrangement of Fig. 1 or the disc 21 in the arrangement of Fig. 3 with very low kinetic energy. However, in practical arrangements of the type shown in Figs. 1 and 3, the electron stream usually gives up only a small fraction of its energy to the field and the remaining energy is wasted in the form of heat generated by the electrons striking the target. In the modification shown in Fig. 6, provision is made for reducing losses of this kind. In the arrangement of Fig. 6 the disc 21 is pierced by an axial hole 23 through which the electron stream may emerge from the resonant chamber. A collecting electrode 24 is maintained at a potential somewhat lower than that of the cylinders 1 and 2, this lower potential being supplied by a battery 25. An axial hole is provided in the right-hand end of cylinder 1 where a conductive tube 26 is attached. The disc 21 is attached to another conductive tube 27 coaxial with tube 26. These two tubes are separated near the right-hand end by an insulating ring 28. The tube 27 extends to the right a little beyond the ring 28 where the end is hermetically sealed with a glass bead or other insulating material through which is also sealed a lead 29 which provides electrical connection to and mechanical support for the anode 24. The cylinder 26 is put through a hole in the wall of the cylindrical guide 16 and the high frequency path across the diameter of the guide 16 is completed from the cylinder 27 by means of a conductive tube 30 which surrounds the lead 29.

The arrangement of Fig. 6 operates substantially in the same manner as that shown in Fig. 3, except that the electrons pass through the hole 23 in disc 21 and are slowed down by the relatively low voltage of anode 24 before striking the anode. The electromagnetic waves emerge from the resonant cavity through the space between the disc 21 and the right-hand wall of cylinder 1 and thence by way of the space between the tubes 26 and 27 and through the insulating ring 28 into the interior of the wave guide 16. The return circuit for the anode 24 is over the lead 29 shielded by the tube 30.

Figs. 7, 8 and 9 illustrate an alternative construction of the resonator which avoids the use of the insulating ring 3 and whatever dielectric loss may be associated with the means for maintaining the desired separation between the cylinders 1 and 2. Although in the arrangements hereinabove described, the amount of dielectric employed is small and what there is may be placed at a nodal point, the arrangements shown in Figs. 7, 8 and 9 completely avoid this source of dielectric loss. In addition these arrangements enable a plurality of electron beams to be used with a single resonator of substantially the same dimensions as those shown in the preceding figures. A further feature of the arrangement is that provision may be made for a voltage step-up between the first and second gaps traversed by the electron beam. Referring to Fig. 7, the outer cylinder is shown at 31. The inner cylinder 32 is held in position coaxial within the cylinder 31

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by studs 33 and 34. Arrangements are provided to accommodate a plurality of electron streams in a cylindrical array about the axis of the resonator. The location of a typical array of electron beams is indicated in Fig. 9 where eight electron gun assemblies are arranged in a circle as indicated at 35. The radius of the circle is approximately a quarter of a wave-length for the waves as propagated in the resonator. The electron guns and associated vacuum tubes, batteries, etc., are essentially the same as for the single electron beam shown in the earlier figures. Each electron beam is provided with aligned apertures and the right-hand wall of the cylinder 31 serves as a common target for all the electron beams. The effective length of the resonating cavity from the stud 33 around peripherally in either direction to the stud 34 is substantially one complete wave-length at the operating frequency. The plurality of electron beams may include any number up to the limit that can be accommodated in the space. The arrangement gives an approximation to the ideal condition of a continuous ring or tubular electron beam. In practice, however, a small number of beams from perhaps six upwards will usually suffice.

It will be noted that in the arrangements of Fig. 1 and other early figures, the intensity of the electromagnetic field at the two gaps traversed by the electron stream is the same. In other words in a velocity variation arrangement according to these figures, the magnitude of the high frequency field which modulates the velocities of the electrons is the same as the magnitude of the field at the point where the energy is extracted from the grouped electrons. This is fundamental to the arrangements so far described. Fig. 8 shows an arrangement whereby this limitation may be avoided. The resonant cavity on the left-hand side in Fig. 8, instead of extending substantially to the axis, is terminated by a cylindrical wall 36. The wave-length of the resonant cavity extends from the wall 36 radially outward, then axially between the cylindrical walls 31 and 32 and thence radially inward to the stud 34. While the distance from the right-hand gap radially inward to the stud 34 is preferably a quarter wave-length, the distance from the left-hand gap to the cylindrical wall 36 is less than a quarter wave-length and may be designed in any desired proportion with respect to the quarter wave-length. Accordingly, the right-hand gap is located at a voltage anti-node as in the case of Fig. 1, but the left-hand gap where the electron velocities are modulated has a substantially smaller voltage impressed across it. In this manner a voltage step-up may be introduced which can be used advantageously to increase the efficiency of the system.

Figs. 10 and 11 show an arrangement whereby a substantially circular resonant chamber, adjustable for tuning and having electrodes for the accommodation of an electron stream may be inserted in a rectangular section of wave guide. The walls of the guide are shown at 34. One end of the resonator is formed by a block 35 stationary with respect to the wave guide and having a circular cylindrical portion cut out on the right-hand side. An aperture 36 in the block 35 communicates between the main portion of the wave guide and the circular resonant chamber. The right-hand side of the resonant chamber is closed by means of a slidably mounted block 37 which has a circular cylindrical portion cut from the left-hand side. The block 37 may be ad-

justed in position by any suitable screw-threaded device operated by means of a handle 98. Conical apertured electrodes 99 and 100 are set into the upper and lower walls of the wave guide near the center of the circular cylindrical enclosure between the blocks 95 and 97. The gap between the electrodes 99 and 100 may be a modulating gap or an output gap according to the desired application. The tuning feature of the resonator is advantageous when it is designed to operate a system at any selected frequency over a predetermined range of frequencies.

Fig. 12 shows a resonant system corresponding generally to the resonator of Fig. 1 with provision for an electron beam to be introduced, sections of rectangular wave guide being employed, however, in place of concentric cylindrical shells. The wall 101 encloses the entire structure and serves to hold the inner portions of the structure in place without the use of any insulating members.

The arrangement of Fig. 12 consists of two rectangular guides 150, 151, 152 and 153, 154, 155 of width somewhat greater than $\lambda_a/2$, where λ_a is the free-space wave-length, and of length equal to $\lambda_g/2$, where λ_g is the corresponding wave-length in the guide. These are folded in the manner shown so that their ends are juxtaposed at gaps 156 and 157. A rectangular box 158 of width somewhat less than $\lambda_a/2$ joins the two guides, and constitutes a "drift tube." An electron stream in the form of a sheet enters from an electron gun comprising a linearly extended cathode 102. The electron sheet passes across gap 156, where it receives a velocity variation, and then, after electron bunching has occurred in the drift tube 158, it crosses the gap 157 where it delivers energy to the system. It will be noted that no dielectric material is required to support parts within the resonant chamber. Also, by virtue of the linear extension of the electron source to dimensions approximating a half wave-length, the system is enabled to utilize very large values of electron current. In order to fix the nodal points of the oscillation at such points that the gaps 156 and 157 will be at loops of the standing wave in the resonant system, partial transverse barriers 104 and 105 may be provided. In practice, the cathode 102 may have an active length of approximately one-half of the free-space wave-length before complications due to the length of the filament begin to cause trouble. Coupling arrangements, electron collector and hermetic sealing are not shown but may readily be supplied in any suitable manner.

Fig. 13 shows a somewhat similar arrangement except that the lower side of the rectangular arrangement of wave guides is omitted and tuning systems 106 and 107 are used to close off the otherwise open end of the wave guide. A rectangular guide 160, 161, 162, 163, 164 of width somewhat greater than $\lambda_a/2$ is provided with transverse slits 165, 166, 167 and 168 in the walls, and folded over in such fashion that the slits are aligned. The two folded portions are connected by a drift tube 169, and an electron sheet is projected through the slits. The pistons 106 and 107 are adjusted to give the guide an effective length of approximately λ_g . In general, the distance from the gap 167, 168 to the piston 107 will be made equal to substantially $\lambda_g/4$, so that at the gap 167, 168 there may exist the maximum field intensity. For best efficiency the distance from the gap 165, 166 to the piston 106 is usually less than $\lambda_g/4$. If desired, the guide section 161, 162,

163 may be made adjustable by means of trombone-type sliding joints so that when the distance from the gap 165, 166 to piston 106 has been adjusted, a final tuning adjustment may be made by tuning the trombone section 161, 162, 163. The linearly extended cathode is accommodated as in the arrangement of Fig. 12.

Fig. 14 shows in more detail the relation of the cathode 102 to the guide and includes a cathode heating battery 103.

The use of the linear cathode to increase the power capacity of an oscillator or amplifier may be extended to types of structures other than those having two gaps to be traversed by electrons and operating upon the velocity variation principle. For example, a diode oscillator of the type disclosed by F. B. Llewellyn in U. S. Patent 2,190,668, issued February 20, 1940, may be built into a section of square or rectangular wave guide as shown in Figs. 15 and 16. The filament or cathode heater 120 extends across the entire width of the guide and is accessible to the outside at its ends which may protrude through insulating bushings. An electron emitter 121 may be placed in proximity to the filament 120 and the emitter preferably extends substantially across the width of the guide, but is insulated from the guide as by means of a support 122. Conductive partitions 123 and 124 for constricting the guide are conductively connected to the side walls and extend from side to side. Insulated focussing electrodes 125 and 126 are set into the member 123 and are separated by a gap 127 transverse to the longitudinal axis of the guide. Another gap 128 extends transversely through the member 124 and below the gap 128 is fastened an insulated electron collector 129. The vacuum chamber may be closed by an insulating partition 130, which may be of glass, and a conductive end wall 131. At a distance to the left of the gap 127 and symmetrical with wall 131 may be located a coupling iris 132, preferably outside of the vacuum chamber. The batteries 133, 134, 135 and 136, as shown in Fig. 15A are employed respectively for filament heating, applying focussing potential to electrodes 125 and 126, applying accelerating potential to the members 123 and 124, and applying a retarding potential to the collector 129. The battery connections, shown in Fig. 15A, are omitted from Fig. 15 for greater clarity.

The operation of the device of Figs. 15 and 15A is similar to that of the arrangement of Fig. 10 of the Llewellyn patent, above cited. The spacing between wall 131 and iris 132 is determined so as to make the wave guide section to the right of the iris 132 resonant at a desired operating frequency. The spacing in the restricted portion between members 123 and 124 is arranged in conjunction with the accelerating potential to provide an electron transit time between 123 and 124 equal to substantially $5/4$, $9/4$ or $13/4$, etc., cycles at the operating frequency, as explained by Llewellyn. Electrons from the cathode 121 are focussed through the gap or slit 127 into the gap between the members 123 and 124 which gap, as mentioned, is of such length that a critical transit time relation for the production of negative resistance in the electron stream is satisfied. After next passing through the second slit 128, the electrons are collected by the electrode 129. When the system is properly adjusted, high frequency energy from the resonant section may be supplied to an external load through iris 132

and the portion of wave guide extending to the left of the iris.

Fig. 16 shows an extension of the arrangement of Fig. 15, wherein several gaps are provided, to be traversed successively by the electron stream, each gap having the proper length to individually satisfy the critical transit time relation. When properly adjusted each gap supplies energy to sustain the oscillations in the resonant section of guide. The gaps are formed between the members 123 and 124 by the introduction of apertured plates as indicated at 137 and 138.

Fig. 17 shows an oscillator in which a wave guide is bent around in a U-shape so as to intercept the electron stream at two points determined by the gaps 108 and 109. A piston 110 and an iris 113 are adjusted to positions approximately one-quarter wave-length either side of the gap 109 as shown, and irises 111 and 112 are placed at approximately quarter wave-length distances either side of the gap 108. With proper adjustment the interaction of the system with an electron stream in the gaps 108 and 109 will result in standing waves being maintained in the wave guide between the piston 110 and the iris 111. It has been found that when the iris apertures are small and the losses in the walls of the wave guide small, a standing wave of very high amplitude is readily maintained either between 111 and 112 or between 110 and 113. By adjusting the position of the piston 110 the two resonators may be made to have the same frequency. The bent section 114 serves to couple the two resonators and constitutes a feedback line or guide. A substantially pure traveling wave with practically no reflection or attenuation is set up in the section 114 and sustained oscillations are readily maintained in the system by interaction between the electron stream and the electromagnetic fields in the gaps 108 and 109. The section 114 may be of any convenient length and is preferably adjustable as by means of a trombone-type slide, so that the relative phases of the oscillations in the input and output stages can be given a suitable value.

What is claimed is:

1. A resonator comprising a hollow cylindrical shell of conductive material substantially closed by plane conductive end plates, and a coaxial cylindrical conductive core of slightly shorter length and slightly smaller diameter than said shell, said core being positioned within said shell and spaced therefrom by means comprising coaxial cylindrical conductive spacers at either end of said core, said spacers being of materially different radius at the two ends of the core.

2. A toroidal hollow resonator of substantially U-shaped cross section having aligned apertures on a line parallel to the axis of said resonator at a distance from said axis substantially equal to a quarter wave-length of the electromagnetic wave to which said resonator is resonant.

3. A toroidal hollow resonator of substantially U-shaped cross section having aligned apertures on a plurality of lines parallel to the axis of the resonator, said lines passing through one of the arms of the said U-shaped cross section at substantially a quarter wave-length from one end of the U-shaped resonant space.

4. In combination with a resonator in accordance with claim 3, electron beam-producing means for sending electron beams through a plurality of successions of aligned apertures.

5. A closed hollow resonator having a generally U-shaped sectional configuration, and means

to project a stream of electrons through said resonator successively at points in opposite arms of the U, one of said points being located substantially a quarter wave-length from the end of the respective arm of the U.

6. A folded full wave-length resonant chamber having portions in proximity that are separated by from one-half to three-quarters of a wave-length as determined within the chamber by the standing electromagnetic waves therein, and means to project a stream of electrons into and through one of said portions of the resonant chamber and into the other of said portions.

7. A folded full wave-length resonant chamber having portions in proximity that are separated by from one-half to three-quarters of a wave-length as determined within the chamber by the standing electromagnetic waves therein, and means to project a stream of electrons into and through a portion of said resonant chamber materially less than a quarter wave-length from one extreme limiting portion of said resonant chamber and thereafter into a portion of said resonant chamber substantially at a quarter wave-length from the other extreme limiting portion of said resonant chamber.

8. A full wave-length resonant section of wave guide closed at the ends and having a configuration as if folded upon itself to bring into proximity portions thereof that are separated at least a half wave-length as measured along the length of the wave guide, and means to project an electron stream through said resonant section at one of said portions and into said resonant section again at the other of said portions.

9. A contorted full wave-length cavity resonator having portions in proximity that are separated at least a half wave-length as measured within the resonator, and means to project an electron stream through said resonator at one of said portions and into said resonator again at the other of said portions.

10. A cavity resonator of integral wave-length, closed at the ends and folded upon itself to bring into proximity portions of said resonator separated at least a half wave-length as measured within the resonator, and means to project an electron stream through said resonant section at one of said portions and into said resonant section again at the other of said portions.

11. A length of wave guide substantially closed at the ends and folded upon itself, and means to project an electron stream successively through said wave guide at one point and into the said wave guide again at a point in the opposite fold.

12. A hollow outer cylindrical conductor, a pair of conductive end plates therefor, an inner cylindrical conductor within said hollow conductor, said inner cylindrical conductor having conductive end surfaces, a pair of cylindrical conductive connectors of different radii less than the radius of said inner cylindrical conductor connecting the end surfaces of said inner cylindrical conductor with the respective end plates of said outer cylindrical conductor at either end, whereby a resonant chamber is defined by said inner and outer cylindrical conductors, the end surfaces of said inner cylindrical conductor and the end plates of said outer cylindrical conductor together with the said connectors, and means to project a stream of electrons through the said end plate adjacent the cylindrical connector of larger radius into and through a portion of said resonant chamber, through the interior of said

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inner cylindrical conductor and into another portion of said resonant chamber, said electron stream lying parallel to the common axis of said cylindrical conductors.

13. A hollow resonator comprising the space between an outer hollow cylinder with plane ends, and an inner coaxial cylinder with plane ends, except as limited by a cylindrical spacer at either end, said spacers being of unequal radii.

14. A hollow outer cylindrical conductor, a pair of conductive end plates therefor, an inner cylindrical conductor within said hollow conductor, said inner cylindrical conductor having conductive end surfaces, a pair of cylindrical conductive connectors of unequal radius, each of said connectors being of radius less than the said inner

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cylindrical conductor, and said connectors connecting the end surfaces of said inner cylindrical conductor with the respective end plates of said outer cylindrical conductor at either end, where-
 by a resonant chamber is defined by said inner and outer cylindrical conductors, the end surfaces of said inner cylindrical conductor and the end plates of said outer cylindrical conductor together with the said connectors, and means to project a stream of electrons through one of said end plates into and through a portion of said resonant chamber, through the interior of said inner cylindrical conductor and into another portion of said resonant chamber.

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